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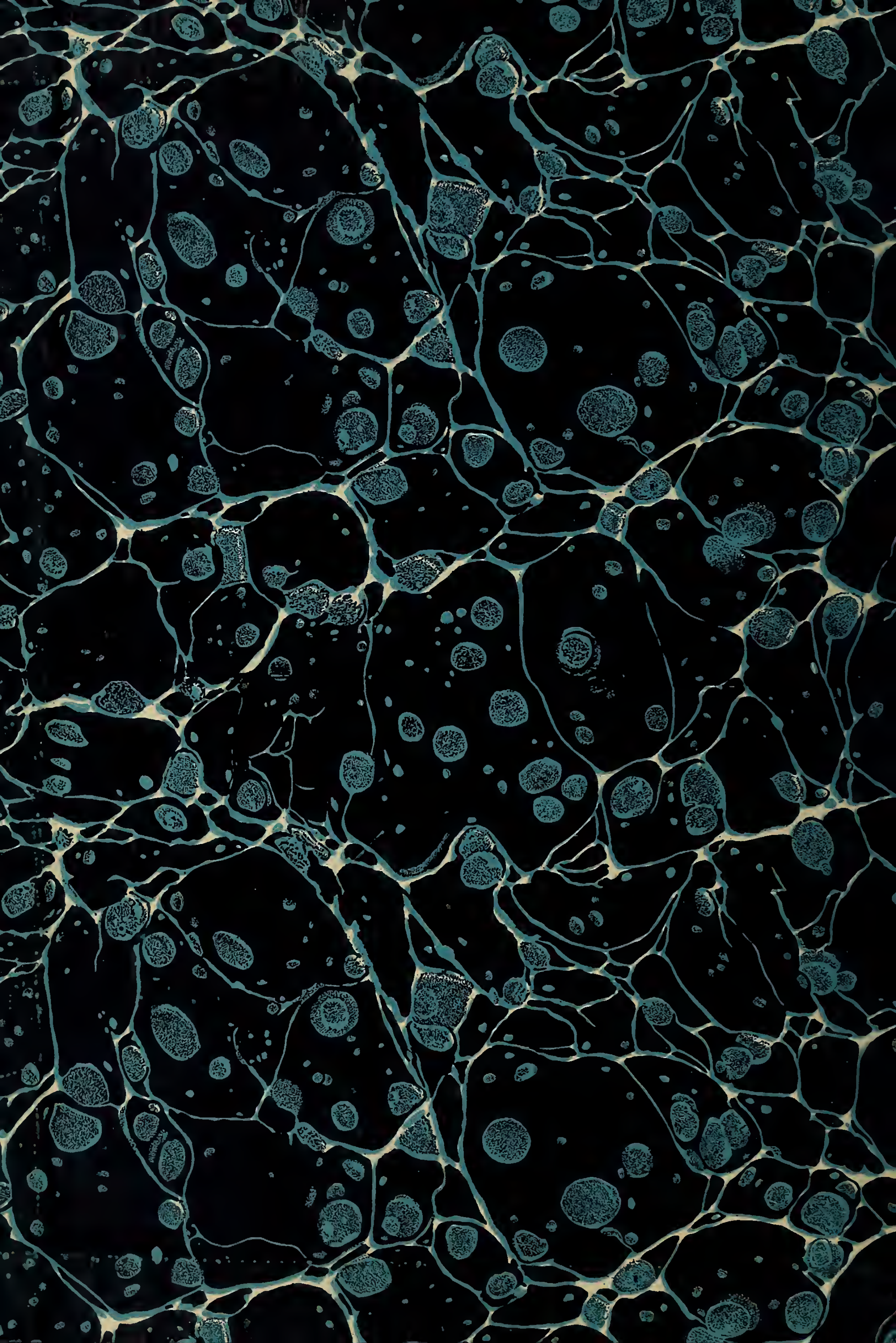

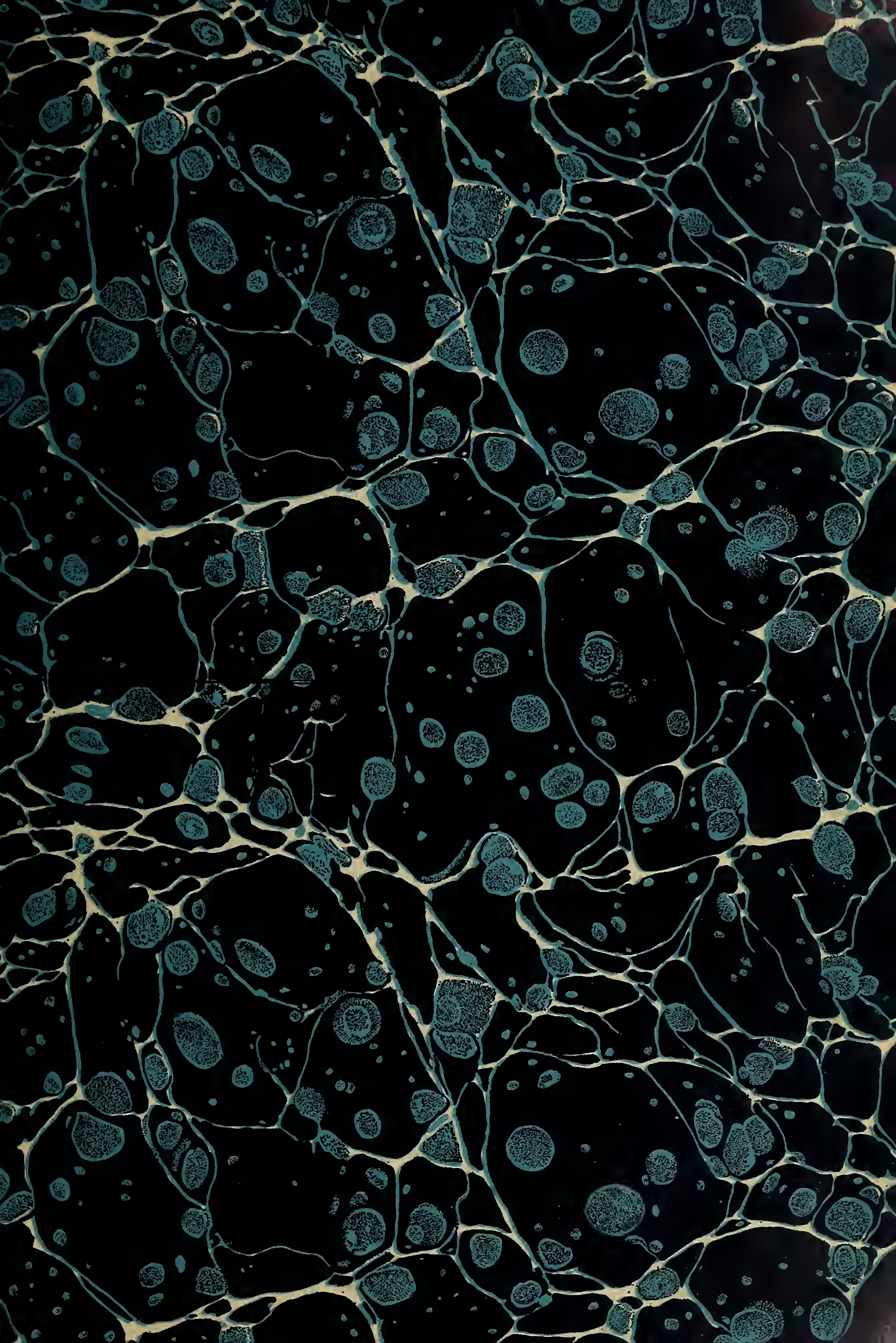

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 151

LOAD STRAIN-GAGE TEST OF 150-TON FLOATING CRANE FOR THE BUREAU OF YARDS AND DOCKS U. S. NAVY DEPARTMENT

BY

LOUIS J. LARSON, Assistant Engineer Physicist
RICHARD L. TEMPLIN, Assistant Engineer Physicist
Bureau of Standards

ISSUED MARCH 18, 1920

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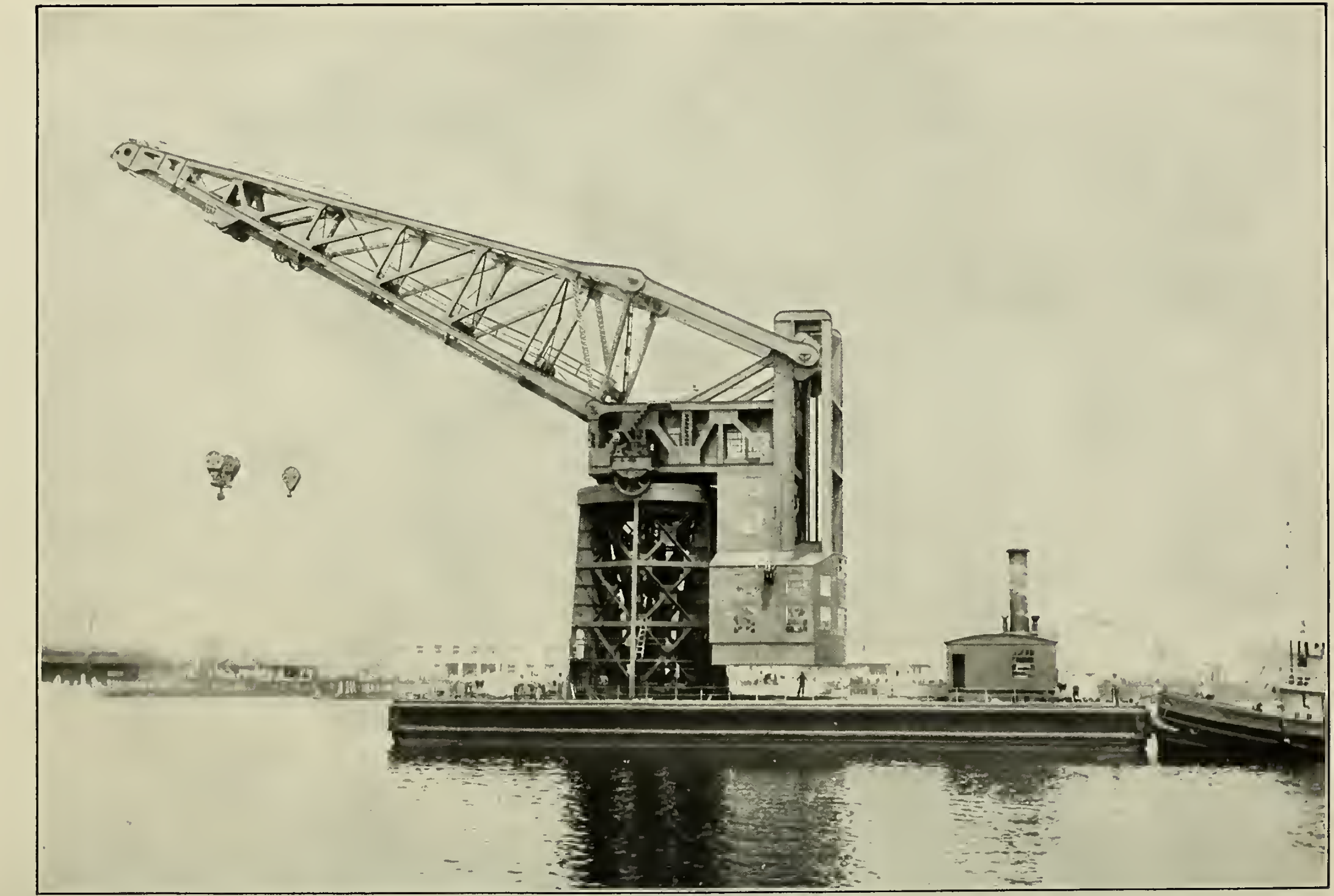

FIG. 1.—*Crane under no load*

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LOAD-STRAIN GAGE TEST OF 150-TON FLOATING CRANE FOR THE BUREAU OF YARDS AND DOCKS, U. S. NAVY DEPARTMENT

By Louis J. Larson and Richard L. Templin

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I. INTRODUCTION

1. PURPOSE OF TEST

At the request of the Bureau of Yards and Docks of the Navy Department, arrangements were made to take strain-gage measurements on some of the important members of a 150-ton (336 000-pound) revolving, floating crane built for use in the navy yard at Norfolk, Va. The test was of special interest and importance to the Navy Department for two reasons: (1) The structure as a whole is statically indeterminate; and a wide difference of opinion as to the distribution of stress among the various members of the crane while under load was found to exist among engineers who had been engaged in designing and checking the structure. (2) The importance of having a more complete knowledge of the loads carried by the various members was forcibly emphasized by the failure of a similar structure built for use on the Panama Canal.[1]

Furthermore, the size of the structure and the unknown behavior of some of its members made a strain-gage test very desirable.

All of the strain-gage measurements were made by the authors. The Norfolk Navy Yard furnished men for recording the data taken, the material and labor for proof loading the structure, and the photographs reproduced in this report.

The engineers who operated the crane mechanism during the test were furnished by the Wellman-Seaver-Morgan Co., the builders of the crane.

The Bureau of Yards and Docks cooperated in selecting the members on which the strain-gage measurements were taken and furnished the necessary data and drawings.

2. DESCRIPTION OF THE CRANE

The crane, as a whole, represents the most advanced type of revolving floating cranes of large capacity.

The jib of the crane is essentially a tapering Pratt truss hinged to the superstructure at the lower chord and connected to the luffing screws at the upper chord by suitable links. The length of the links and the location of the luffiing screws are such that a nearly direct pull is exerted on the upper chord of the jib for all positions.

The superstructure, exclusive of the jib, consists of two subdivided triangular trusses rigidly connected by cross bracing. In addition to supporting the jib arm the trusses carry the machinery house and jib-arm counterweight on the ends opposite the jib arm. The entire revolving load is transmitted by the triangular trusses to the pontoon through a pintle.

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[1] Eng. News, p. 913, May 13, 1915.

The pintle is an inverted pyramidal-shaped member, built up of four posts, which transmits its load at the apex to a thrust bearing on the deck of the pontoon.

A tower, consisting of six legs, arranged in the form of a hexagon, supports this pintle laterally. The legs of this tower are carried through the deck to the framing of the pontoon. The system of bracing between the legs is intended to make the whole structure of the tower act as a unit. The entire tower will then deform under load as a cantilever beam instead of allowing the individual columns to carry the lateral forces independently. Further, the tower is framed into the hull in such a manner as to make the pontoon act as a large girder in resisting the forces induced by a crane load.

The lateral thrust at the top of the tower is transmitted to the pintle through rollers running on circular tracks framed between the tower columns and pintle posts. The pintle, rotating within the tower, makes it possible to revolve the superstructure with the live load to any position.

Throughout the full horizontal movement of the crane the jib may be raised through an angle of approximately 52° from its lowest position, at which position the lower chord of the jib makes an angle of approximately 27° with the horizontal.

II. PROCEDURE OF TEST

1. PREPARATION FOR TEST

The members about which it was desired to secure information concerning the amount of stress developed in transmitting the crane load to the pontoon, were chosen after a study of the drawings and a discussion with the Bureau of Yards and Docks, Navy Department.

(*a*) MEMBERS IN WHICH STRESSES WERE MEASURED—It was decided to take readings—

1. At various points on the deck, to determine the magnitude and if possible the position of maximum stress in the upper deck plate.

2. On the tower members, to determine whether the tower acted as a unit.

3. Around the manhole in the tower legs, to find the effect of such an opening.

4. On the pintle, to determine the magnitude of the stress in these members.

5. On various members of the superstructure, to determine the manner in which the loads were carried down to the pintle. Considerable difference of opinion existed among designers as to which members would carry the applied loads. The jib member (gage lines *C 1*, *C 2*, *C 3*, and *C 4*) attracted particular interest because of the failure of the corresponding member in the crane built for the Panama Canal.

(*b*) LOCATION AND NUMBERING OF GAGE LINES.—Gage lines were always placed on two opposite sides of every member tested and, where possible, on all four sides to detect any bending. The location of the gage lines is shown in Fig. 15.

(*c*) SUPERSTRUCTURE GAGE LINES.—In general, for the superstructure, where two gage lines are shown on the same side of a member, the odd numbers are on the outer and the even numbers are on the inner side.

Gage lines *C 1*, *C 2*, *C 3*, and *C 4* are located 6 inches above the gusset plate at the lower end of the member.

Gage lines *R 1*, *R 2*, *R 3*, and *R 4* were located on the edge of the cover plate and about 2 inches from the end of the upper gusset plate. *R 13* and *R 14* were near the middle of the strut. *R 5*, *R 6*, *R 7*, and *R 8* were located about 7 inches below the upper splice plate. Gage lines *R 9*, *R 10*, *R 11*, and *R 12* were on the right (when facing jib) diagonal of front cross truss. They were located about 20 inches from the lower gusset plate. *R 15*, *R 16*, *R 17*, and *R 18* were similarly located on the right (facing jib), diagonal of the truss framing into the rear pintle post. In this one case *R 15* and *R 16* are below the member, and *R 17* and *R 18* are above, the odd numbers in each case being on the inside.

(*d*) PINTLE GAGE LINES.—In numbering the gage lines on the pintle, the following scheme was followed throughout. Standing within the pintle and facing the jib the pintle post in front was called post No. 1. Proceeding in a clockwise direction gage line *P 1* is on the left side of post No. 1 and gage line *P 2* is on the right side. The remaining posts are numbered *2*, *3*, and *4*. Similarly, the gage lines on the other posts are numbered *3*, *4*, *5*, *6*, *7*, and *8*, respectively, for the lower tier. The second and third tiers are similarly numbered from *P 11* to *P 18*, and from *P 21* to

P 28, respectively. The gage lines for each tier were located near the midheight of the panels of the pintle as formed by the diagonal bracing.

(*e*) DECK GAGE LINES.—The gage lines on the deck of the pontoon were laid out for the purpose of checking the computed locations of the maximum bending moments and the stresses. With a load of 150 tons, and jib in center-line position, the maximum bending moment as computed should be 40 feet from center of tower, on the center line of the pontoon, between the tower and the engine house. At this location a gage line *D 2*, was placed and 2 feet each side of it, on the same center line, gage lines *D 1* and *D 3* were placed. Other gage lines, *D 4*, *D 5*, *D 6*, *D 7*, *D*, *8* and *D 9* were placed over the longitudinal bulkheads and girders of the pontoon to the right of the center line looking forward, parallel to the gage lines *D 1*, *D 2*, and *D 3* and in the same relative positions. For checking the bending moment and deck stresses with jib abeam, the gage lines *D 21*, *D 22*, *D 23*, *D 24*, *D 25*, *D 26*, *D 27*, and *D 28*, were placed over the center cross bulkhead adjacent and at right angles to the longitudinal deck gage lines previously mentioned. (See Fig. 2.) Four gage lines, *D 31*, *D 32*, *D 33*, and *D 34*, were located at the forward corners of the engine house to determine whether there were excessive stresses in the deck due to discontinuity of the deck plates. These gage lines were placed in pairs at right angles to each other in order to determine the stress in both directions.

(*f*) TOWER LEG GAGE LINES.—Strain-gage readings were taken upon two opposite tower legs. The forward tower leg was to the right and the aft tower leg to the left of the center line of pontoon. Readings were taken at two levels on each tower leg. The lower set of readings was taken between the first and second levels of horizontal lateral bracing, where the manholes or passageways are cut in the tower legs, and the upper set was taken just above the second level of horizontal lateral bracing. The gage lines were arranged in pairs so that all the odd numbers are on one side of the tower legs and the even numbers on the other—that is, *T 2* is opposite *T 1*, *T 4* opposite *T 3*, etc. Readings were taken on the outer flanges, on the web adjacent to the manhole, and on the inner flanges of the tower leg at the lower level, and on the outer and inner flanges of the tower leg at the upper level. (See Fig. 3.)

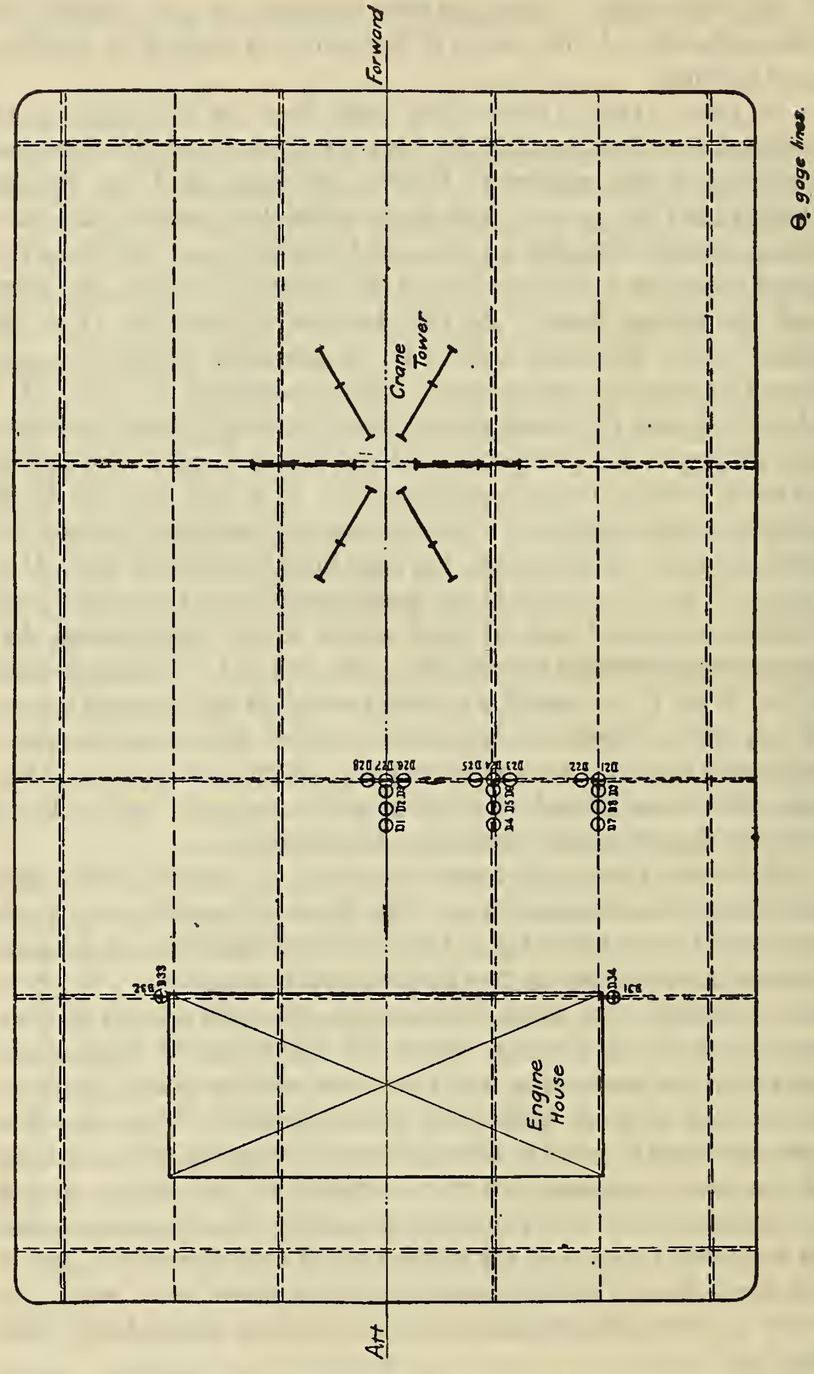
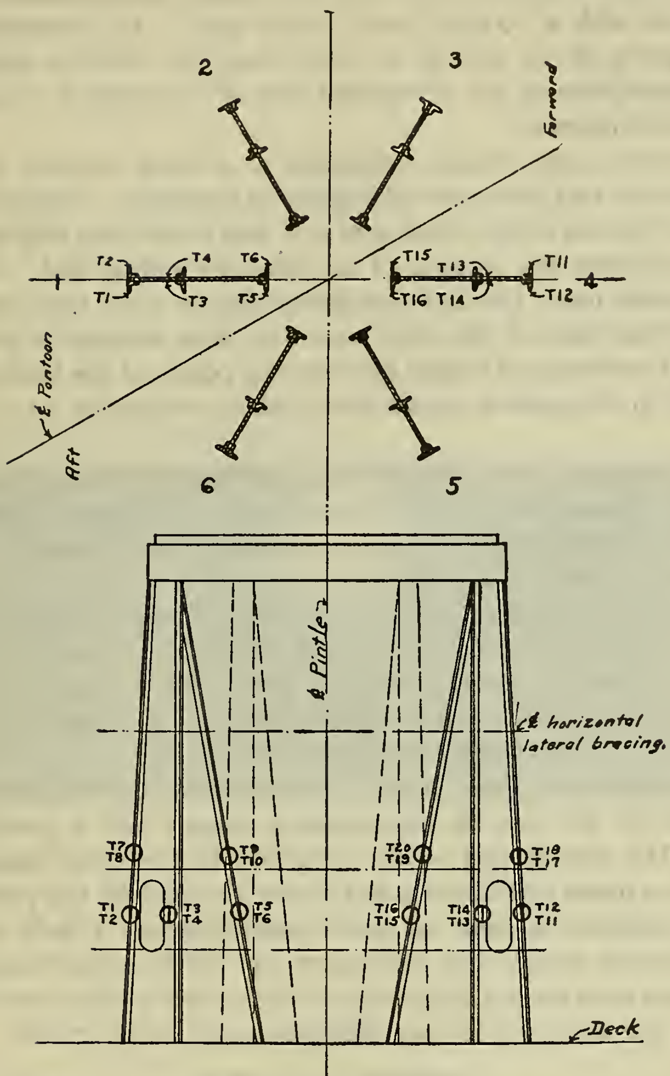


FIG. 2.—*Deck plan of 150-ton floating crane pontoon, showing location of strain-gage readings*



Note:- Gage lines T21 & T22 are on upper and lower edges of the lower end of diagonal lateral bracing extending between tower posts No. 4 and No. 5.

⊖ Gage lines-on opposite sides of member. Upper number on near side, lower on far side of member.

FIG. 3.—*Sketch of tower of crane, showing location of gage lines*

2. INSTRUMENTS USED

(*a*) BERRY STRAIN GAGE.—The strain-gage measurements were all taken with a 10-inch Berry strain gage. An instrument of this type is shown in Fig. 4. For those not familiar with it a brief description of the instrument and of the method of using it may be of interest.

The strain gage consists essentially of a frame carrying a fixed point at one end and a movable point at the other. The movable point is the end of the short arm of a bell crank, the long arm of which actuates the plunger of an Ames indicating dial. In the instruments used, the dial was graduated to 0.001 inch and the multiplying ratio of the lever was five, thus making it possible to read the change of length between the points of the instrument directly to the nearest 0.0002 inch and by estimation to 0.00002 inch.

The gage lines were established by drilling small holes 10 inches between centers with a No. 56 twist drill. The holes, forming a gage line, must be on the same element of the member if the longitudinal stress in the member is desired.

In making an observation, the points of the instrument are inserted in the gage holes and the resulting dial reading recorded. It is evident that the changes in length for various load conditions as indicated by such dial readings will give the data from which the stress in the member may be computed.

(*b*) DEFLECTION READINGS.—The deflection of the tower was obtained by the use of an engineer's transit and a graduated scale. The transit was rigidly attached to the outer flange of one of the tower legs about 5 feet above the deck of the pontoon. It was adjusted to sight on scales graduated to 0.1 inch, which were securely attached to the upper end of the same tower leg. The scales were set at right angles to each other so that the movement of the tower leg in two directions could be observed.

3. METHOD OF LOADING

The material used for loading the crane consisted principally of armor plate and scrap iron. The weight of the pieces was known so that the desired load could be lifted by the hoisting hook.

4. LOADING SCHEDULE

The schedule of loading was so chosen that each member on which measurements were to be taken was subjected to the maximum possible range of stress.

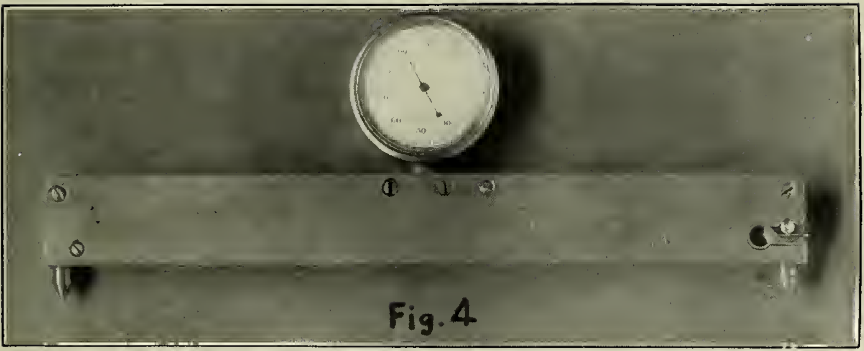


FIG. 4.—*Berry strain gage*

It is evident from an inspection of the crane that the minimum stress or maximum reversed stress occurs with the jib in its highest position with no live load being lifted. In this position the positive moment due to the dead weight of the jib is greatly reduced. For this reason the initial strain-gage measurements were taken with the jib up. Observations were then made with the jib down under the three conditions of no load, 150-ton (long) hook load, and 180-ton hook load.

It was also desired to find the effect of changing the jib location from the center line (over the end of the pontoon) to a position abeam (over the side of the pontoon). Readings were therefore taken on the members affected by this change with the jib located in both positions.

To get the maximum stress in a leg of the tower, a set of observations was made on these members when the jib was located directly over them. No readings were taken on members in which no change of stress was expected.

(*a*) TABLE OF LOADING.—The following table gives concisely the conditions of loading and the gage lines on which observations were made:

TABLE 1.—Conditions of Loading and the Gage Lines on Which Observations Were Made

Load in tons	Position on jib	Reading on members
0	Jib up on center line	All members.
0	Jib down on center line	Do.
0	Jib up abeam	Tower and deck.
150	Jib down on center line	All members.
150	Jib down abeam	Tower and deck.
180	Jib down on center line	All members.
180	Jib down abeam	Tower and deck.
180	Jib down over post	Tower.

For their own information and as a check on their calculations, the Navy Department measured the angle of list in various directions under the several conditions of loading. In this report we are concerned only with the strain-gage and the deflection measurements.

In the position designated as "jib down" this member was in its lowest possible position only under the no-load condition. Under the load the jib was luffed until the reach beyond the edge of the pontoon was the maximum required by the specifications.

III. DISCUSSION OF RESULTS

1. TEST CONDITIONS

It is readily seen that in the determination of results which depend upon a measurement of the deformation of the material under stress, the temperature and other weather conditions become important factors. A large change of temperature may cause as great a change of length of the member as the application of a load. During this test the weather conditions varied from very hot and clear to cool and rainy.

(*a*) STANDARD BARS.—It is customary to take readings on unstressed bars of the same material as the structure known as "standard bars." From these readings it is presumed that it is possible to correct the test observations for changes due to temperature. The use of these bars also eliminates possible errors due to accidental change in the adjustment of the instrument.

Standard bars serve very well for temperature correction provided their changes correspond to the temperature changes of the members. However, during this test some of the members were in the bright sun and others in the shade when one set of observations was taken; at another time of day, or with the jib in a different position, the conditions might be reversed, thus making it impossible to place the standard bars so that their temperature would be representative of that of all the members.

Conditions were further complicated by a rain which caused many of the gage holes to rust, thus probably changing the readings to some extent.

2. METHOD OF REDUCING DATA

A preliminary analysis of the data showed that corrections based upon the standard bar readings gave quite satisfactory results for for practically all cases. However, in the case of the 150-ton load, the indicated stresses in the pintle and superstructure appeared to be about 2000 pound per square inch too low in compression and an equal amount too high in tension when compared with those obtained for the zero and 180-ton load. Since the magnitude and sign of the correction which appeared to be required was practically the same for all members whether subjected to a large or small stress, to tension or compression, it seems logical to apply such a correction especially in view of the conditions under which the test was conducted. This correction has therefore been made throughout the computations for this report.

In the case of the deflection readings on the tower an adjustment was found necessary. The observations taken as the loading proceeded have been discarded, as it was found that the instrument was generally disturbed between consecutive observations. The deflection observations, taken as the jib was continuously rotated with the 180-ton load, have been used in this report. Although the actual zero for this set could not be obtained directly, the readings are considered reliable, since the instrument was not disturbed. The zero deflection, in each direction, was assumed as midway between the extremes and the deflection readings adjusted accordingly.

(*a*) ASSUMED NO LOAD CONDITION.—It will be recalled (see loading schedule) that the initial strain-gage readings were taken with the jib in its highest position with no load on the hook and in making the stress calculations this condition has been assumed to give zero stress. For convenience in plotting the load-stress curves the condition of the jib in its lowest position with no hook load was considered the condition of no load on the structure. It was therefore necessary to calculate a hook load that would produce stresses in the structure equivalent to that caused by lowering the jib. This calculation was based on the data (see Fig. 5) obtained from the blue prints of the crane as submitted by the Bureau of Yards and Docks.

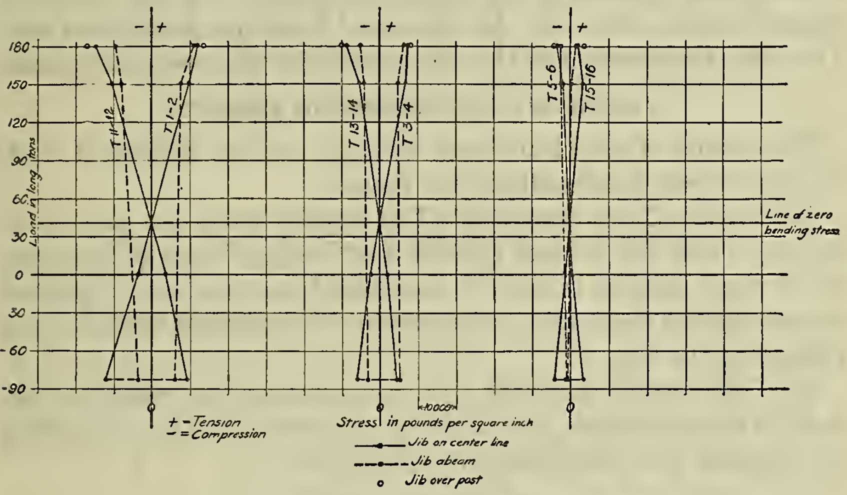


FIG. 5.—*Averuge load-stress curves for tower legs*

For the members of the pintle and superstructure, the horizontal reactions at the base of the pintle were used, and it was found that the change in stress in the structure of raising the jib from the lowest to the highest position was equivalent to applying a negative load (lift) of 68 tons through the center line of the hook with the jib at its lowest position. Similar calculations showed that an upward reaction of 83 tons at the main hook would be required to offset the stresses produced in the tower and deck by lowering the jib. These calculations should be considered as approximate, since the effect of the direct stress due to the application of the live load as well as the effect due to the small change in the list angle which such a hook load would produce have been neglected. From the values of the dead and live load moments, as furnished by the Bureau of Yards and Docks, it has been calculated that a live load of 40 tons, applied to the jib in its lowest position, is just sufficient to balance the dead loads, thus producing zero-bending stresses in the tower and pintle. All the indicated stresses should, therefore, be measured from the 40-ton load line. This line is shown on all the curve sheets for the tower and pintle.

3. METHOD OF REPRESENTING RESULTS

The results of the strain-gage readings and the deflection readings are shown graphically in the figures.

(*a*) Strain-Gage Results.—The applied loads are plotted as ordinates and the stresses indicated at the gage lines as abscissæ. In all these graphs tension is considered positive and is plotted to the right of the origin; compression is considered negative and plotted to the left.

(*b*) Deflection Results.—In representing the results of deflection measurements, the angles of rotation of the jib are plotted as ordinates and the deflections as abscissæ.

4. TEST RESULTS

(*a*) Deck.—The results of the deck readings will be found on Figs. 6 and 7. The full-line curves represent the stresses obtained with the jib on center line and the dotted-line curves show the corresponding values for the jib abeam. As a reliable indication of the actual stresses developed in the deck, these curves are not satisfactory. It will be seen that a load of 180 tons does not produce a stress proportional to that resulting from the 150-ton load. In many cases the indicated stress is less for the larger load, a condition which is obviously incorrect. The irregularities in the curves are undoubtedly due to the large temperature changes to which the deck was subjected. When exposed to the sun, the deck plate which was covered with asphaltum paint became very hot.

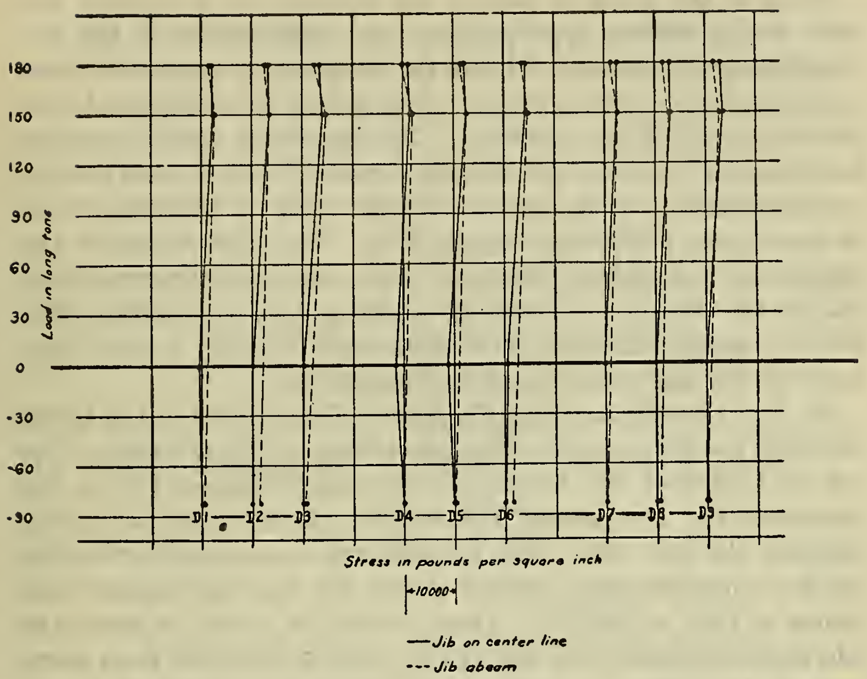


FIG. 6.—*Load-stress curves for deck of pontoon, gage lines D1–D9*

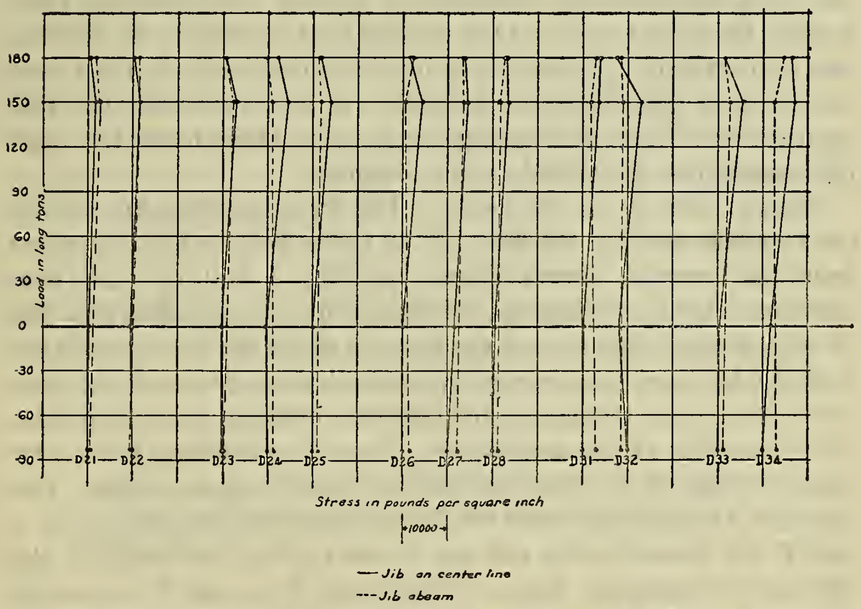


FIG. 7.—*Load-stress curves for deck of pontoon, gage lines D21–D34*

When in the shade of part of the structure or of a cloud, the deck would assume approximately the temperature of the air. Considering the number of times the temperature conditions were actually changed during the test, it is hardly to be expected that the curves should be consistent. The maximum stress indicated is only about 7,000 and the average stress only about 3,000 pounds per square inch. A change of 1° F will cause an indicated stress of nearly 200 pounds per square inch. The uncertainty in the temperature corrections therefore make the actual stress at any load or the variation of stress from load to load unreliable. It is safe to conclude, however, that the margin of safety is more than sufficient for any condition of load on the jib.

(*b*) TOWER.—*Strain Gage Readings.*—The stresses in the tower legs with the jib on center line are shown on Figs. 8 and 9. As will be seen from the location of the gage lines on Fig. 3, the curves on Fig. 8 represent the stresses in the tower leg nearly opposite the jib, while Fig. 9 shows the load-stress curves for the leg under the jib. Similar curves for the "jib abeam" are shown in Figs. 10 and 11. These curves are shown in pairs; the odd numbers are on one side of the tower leg and the even numbers on the other. A comparison of the two curves of a pair shows a very close agreement of stress between the two sides of the tower leg under all conditions of loading. As noted on Figs. 8 and 9, the extra reading at the 180-ton load represents the stresses due to placing the jib directly in line with the posts of the tower on which the gage lines were located. It was expected that this position would give the maximum stress in these tower legs, and this assumption is verified by the readings.

Average Stresses in the Tower.—The stress distribution among the members and the behavior of the tower may be better studied from the average curves shown on Figs. 5 and 12. In these curves the full lines represent the results of readings taken with the jib on the center line or over the forward end of the pontoon and the dotted lines show the stresses with the jib abeam or over the side. Each curve is an average of the stresses obtained on the two sides of the member at the same point. Gage lines similarly located on opposite sides of the tower are plotted from the same origin. For example, the average stress for jib on center line at gage lines *T 1* and *T 2* is shown by the full line to the right of the origin in the first set of curves on Fig. 5. Gage lines *T 11* and *T 12* occupy the same relative position on the opposite side of the tower as *T 1* and *T 2*, and the average stresses obtained from these gage lines

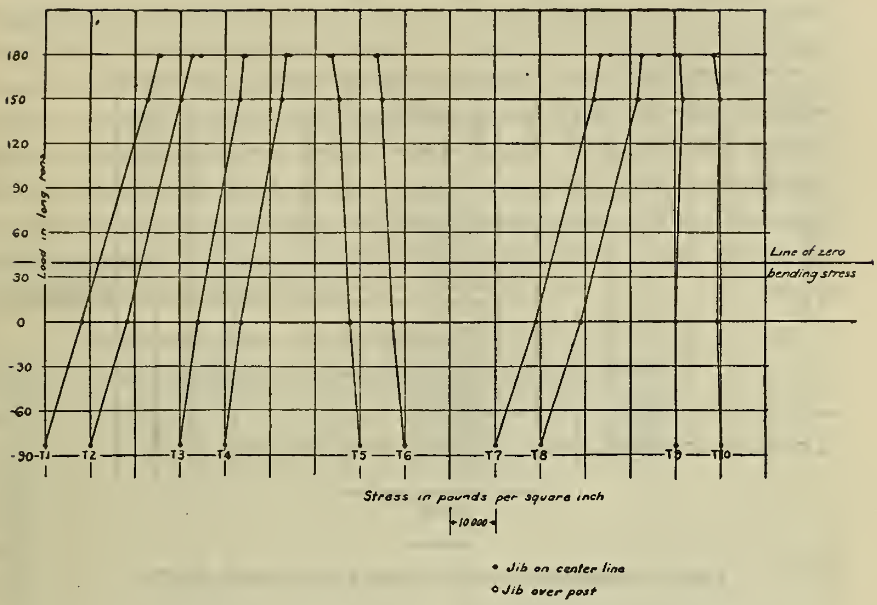


FIG. 8.—*Load-stress curves for tower legs, jib on center line T1–T10*

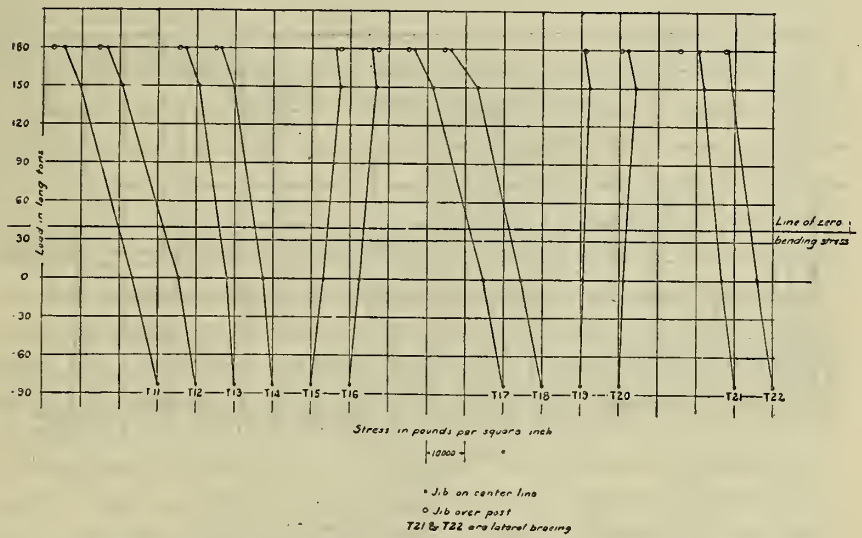


FIG. 9.—*Load-stress curves for tower legs, jib on center line T11–T22*

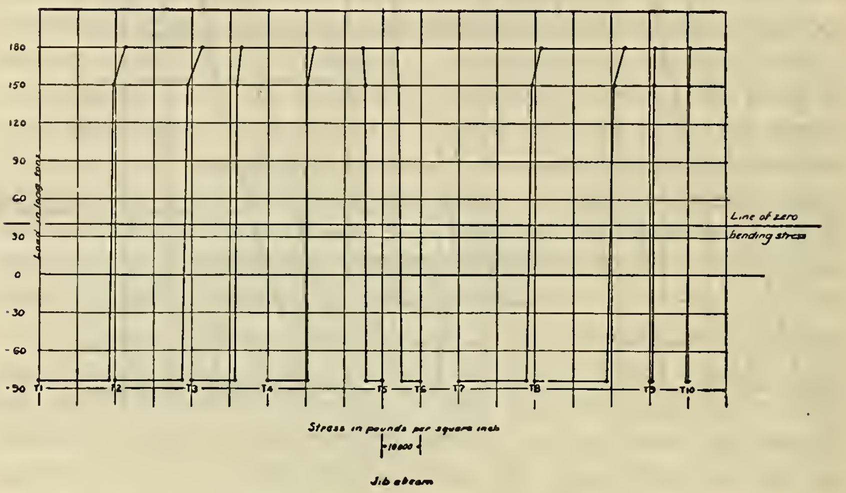


FIG. 10.—*Load-stress curves for tower legs, jib abeam T1–T10*

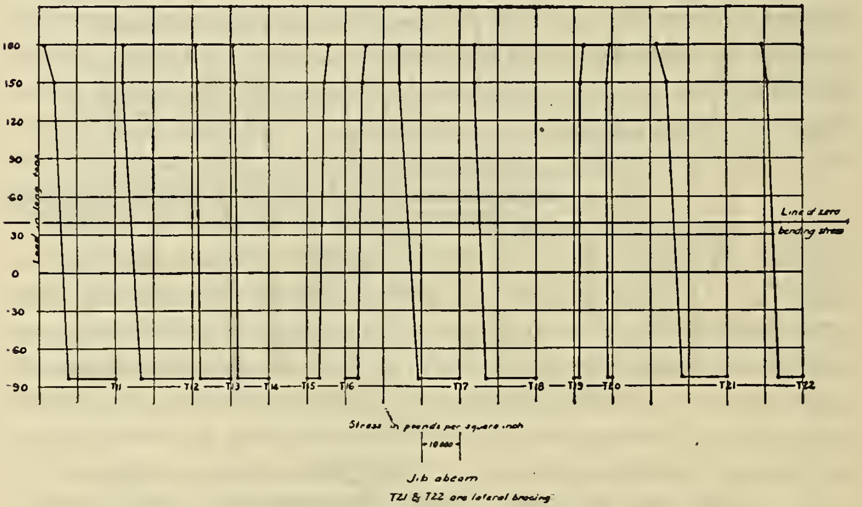


FIG. 11.—*Load-stress curves for tower legs, jib abeam T11–T22*

are therefore represented by the full line to the left of the origin. Similar groups of curves are shown for each location on the tower at which observations were made. From the location of the gage lines it will be seen that the three groups from left to right of curves on Fig. 5 show the conditions of stress at the outer, middle (approximately), and inner edges, respectively, of the tower legs at the level of the center of the manhole. Similarly, the first two groups on Fig. 12 show the stresses at the outer and inner edges of the tower legs at the upper level. (See Fig. 3 for location of tower gage lines.)

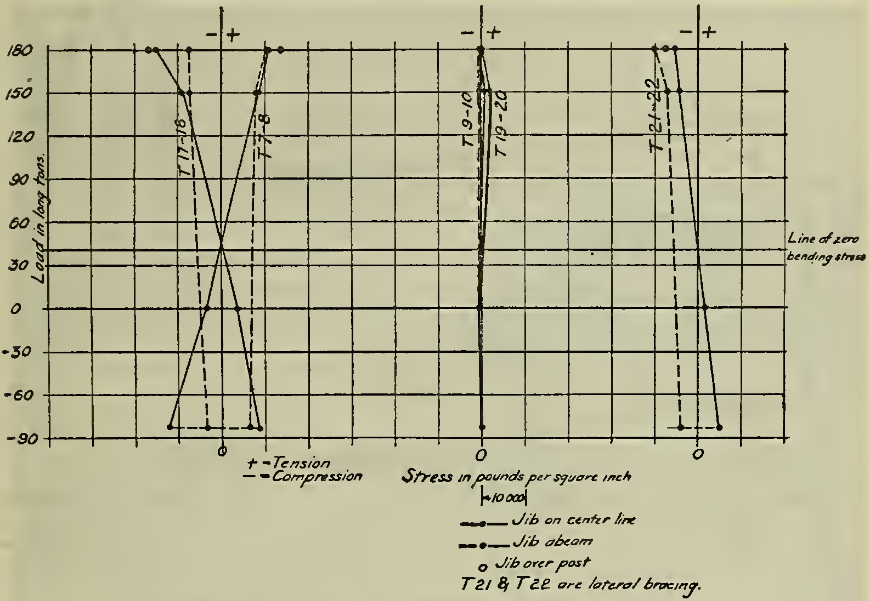


FIG. 12.—*Average load-stress curves for tower legs*

A study of the curves for the jib on center line shows that the stress developed at corresponding points on opposite sides of the tower are equal and opposite within the limits of observational error. It will also be seen that the magnitude of the stress varies considerably across the section of the tower leg.

Distribution of the Stress Across the Tower Leg.—To facilitate a study of the variation of stress across the section of the member, the curves on Fig. 13 have been plotted. These curves show the variation in stress at the various points on the tower legs. At the lower level the stresses decrease from a maximum value at the outer edge of the section to zero at a point approximately 2 feet from the inner edge, and then increase with the opposite sign until the inner edge is reached. At the upper level the point of zero stress, commonly known as the neutral axis, is approximately at the edge of the tower. Although the inner edge of the tower is sloping the neutral plane is almost vertical.

Behavior of the Tower Under Load.—This stress distribution throws some light on the method in which the tower acts. If the entire tower acted as a unit the stresses at opposite edges should be equal and opposite, but the neutral axis should be at the center of the tower. If the individual legs acted as cantilevers the stresses at opposite sides of the tower might still be equal and opposite, but in this case the neutral axis should be near the middle of the member. The curves show that neither of these but rather some intermediate condition exists, which is probably due to a combination of both actions. The proportion of the total stress due to each of the actions can be roughly determined by the fact that the neutral axis is near the edge of the leg. Considering the upper level of gage lines and assuming that the section of the tower leg is symmetrical about the center line, the tension and compression on opposite sides of the tower leg should be equal. In order to reduce the stress to zero at the inner

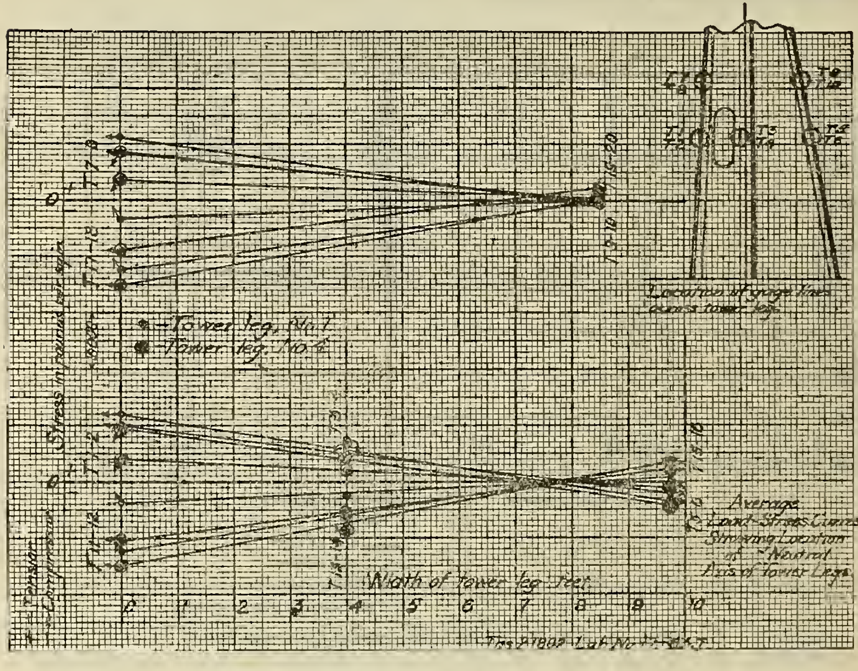


FIG. 13.—*Locations of neutral axes of tower legs*

edge of the tower, it would therefore be necessary to apply a direct stress equal and opposite to the stress due to the bending. Roughly, then, half of the indicated stress at the outer flange of the tower leg is due to the direct stress of the tower acting as whole and the remaining stress is due to the load carried by the tower leg as a cantilever.

The results of observations taken with the jib abeam are not readily explained. The values obtained for both the 180 and 150 ton loads appear reasonable, but the high stresses indicated for the position of jib up with no load can not be accounted for. Inasmuch as the line of the tower legs on which measurements were taken was at an angle of only 30° with the center line of the pontoon, it was expected that there would be a decrease in the stresses as the jib was rotated from the jib on center line to jib abeam position. It has been shown that with no load and the jib in the upper position, the moment on the tower and therefore the stresses in the tower members were actually negative as compared with the moments and stress produced by loading the jib. The decrease expected in the negative stresses would actually appear as positive stresses, and hence the sign of the stresses produced by rotating the jib to the abeam position are correct, but the magnitude appears unreasonably large. No explanation for this behavior is offered.

Magnitude of the Stresses in the Tower.—All the values obtained from the tower gage lines represent positions of the jib within one quadrant of its rotation. It might be assumed that a complete reversal of the jib would cause an equal stress of opposite kind which would result in a range of stress of nearly 50 000 pounds per square inch in some cases. Such a range of stress would clearly be dangerous. Since, however, the zero of the gage lines actually represents a stress of the opposite sign to that resulting from the application of load on the jib, that range of stress caused by rotating the crane will be reduced by twice the amount of the initial stress. It has been shown that the actual stresses should be measured from the 40-ton load line. For the strain gage readings a set of curves showing the stress in the tower plotted against the angle of rotation of the jib from a fixed zero (forward position) point has been plotted for the 180-ton load. These curves are shown on Fig. 14. Although the jib was only rotated through 90° it has been assumed that the readings on the opposite post would represent the stresses obtained by rotating the jib 180°

from each position in which readings were taken. This assumption is justified by the fact that the stresses in corresponding opposite points are equal and opposite in all cases as shown by the average curves. The only questionable part of this procedure is the actual range of stress. It has been shown that this depends primarily upon calculation, for which there is no experimental check except that the calculated load equivalent of lowering the jib, which was based on the same figures, gave a value which agreed closely with the load-stress curves for the individual gage lines.

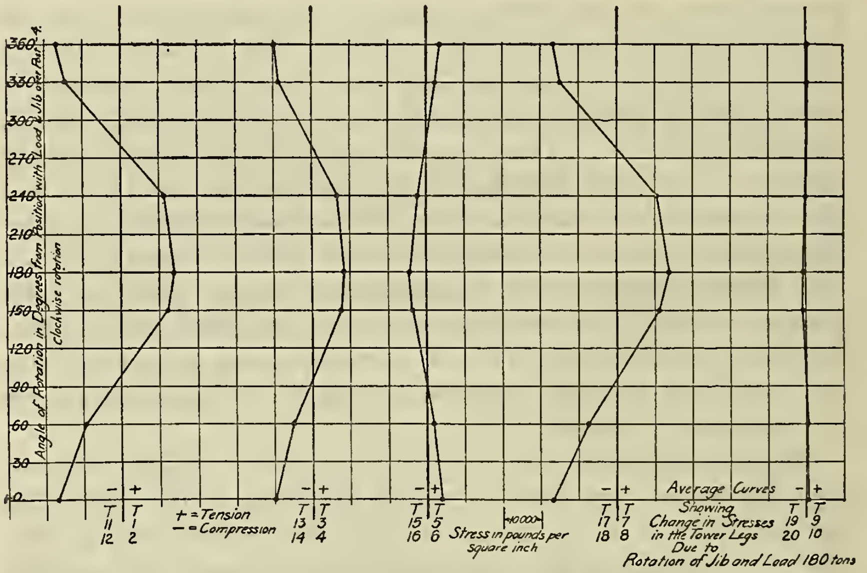
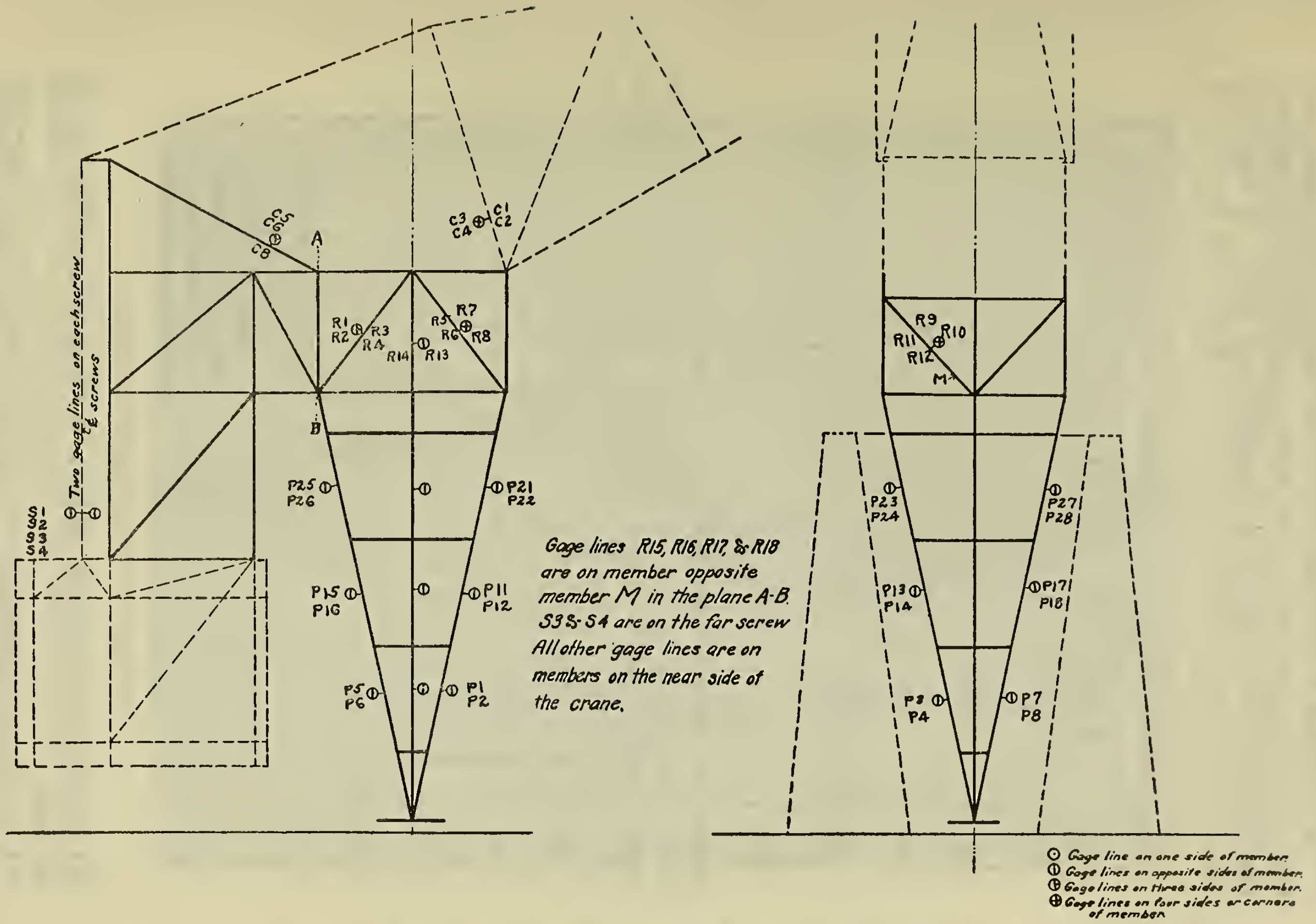


FIG. 14.—*Stress in tower legs under rotating load*

Accepting the calculated values as correct, the stresses vary from 17 000 pounds per square inch in compression to 13 500 pounds per square inch in tension for the 180-ton load. Remembering that the structure with the 180-ton load is carrying an overload of 20 per cent, these stresses may be considered safe.

Deflection Readings.—Deflection readings on the tower were taken on tower post No. 4 (see Fig. 15) and are shown graphically on Fig. 16. One curve shows the deflection in the athwartship direction and the other shows the fore-and-aft deflection. Theoretically these should be sine curves having the maximum and minimum values when the jib is in the direction of the deflection measurements and having zero values when the jib is at right angles to this direction. The curves approach these conditions very closely.


C5
C6
C8
A
B
C3
C4
C1
C2
R1
R2
R3
R4
R14
R13
R5
R6
R7
R8
Two gage lines on each screw
℄ screws
S1
S2
S3
S4
P25
P26
P21
P22
P15
P16
P11
P12
P5
P6
P1
P2
R9
R10
R11
R12
M
P23
P24
P27
P28
P13
P14
P17
P18
P3
P4
P7
P8
Gage line on one side of member.
Gage lines on opposite sides of member.
Gage lines on three sides of member.
Gage lines on four sides or corners of member.

Gage lines R15, R16, R17, & R18 are on member opposite member M in the plane A-B. S3 & S4 are on the far screw All other gage lines are on members on the near side of the crane.

Fig. 15.—*Diagramatic sketch of 150-ton floating crane pintle and adjacent superstructure, showing location of gage lines*

The fact that the athwart-ship deflection was only about one-half as much as the fore-and-aft deflection, supports the assumption that the tower did not act entirely as a unit. A tower leg acting individually would naturally deflect less in the direction of the larger section modulus, which is the athwart-ship direction in this post.

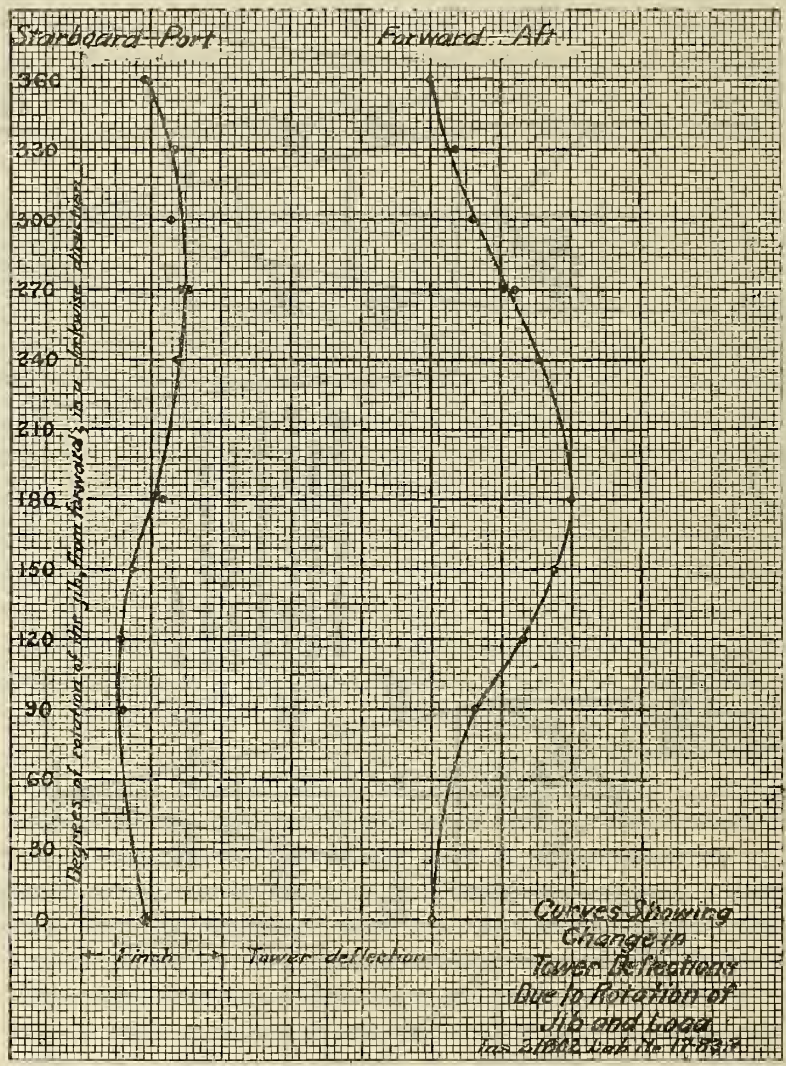


FIG. 16.—*Tower deflections under load*

A maximum deflection of 0.50 inch in the fore-and-aft direction does not appear unreasonably large as compared with 0.25 inch in the athwart-ship direction when it is considered that there is no post directly fore-and-aft to take the bending in this direction to the best advantage.

(*c*) PINTLE.—The stresses in the pintle are shown on Figs. 17 and 18. It will be recalled that gage lines *P 1*, *P 11*, and *P 21* at the first, second, and third levels, respectively, are on the left side (facing the jib) of the front (No. 1) pintle post. Gage lines *P 2*, *P 12*, and *P 22* are located at the corresponding positions on the right side of the member. The curves are similarly grouped for the other pintle posts. A study of these curves shows the stresses to be very nearly equal at the different levels. For the first and the third post there is no consistent difference in the stresses on the two sides of the member. The stress in the first

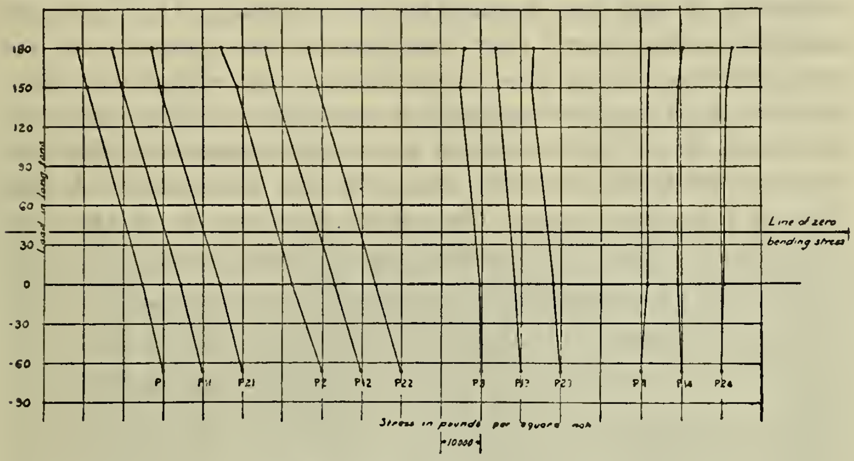


FIG. 17.—*Load-stress curves for pintle*

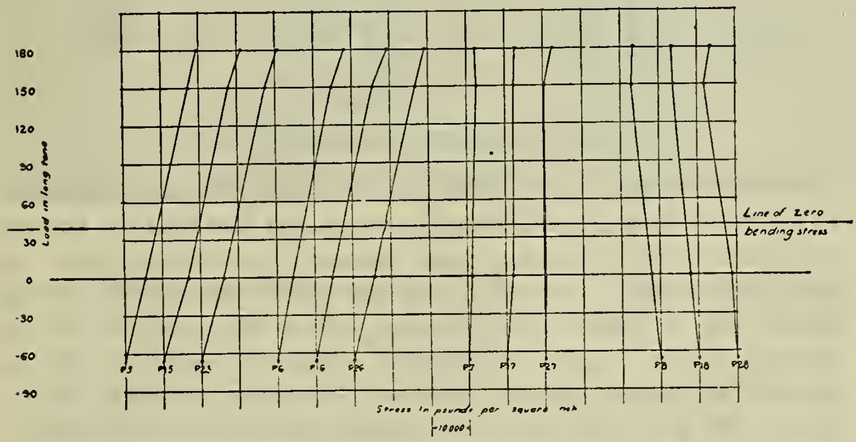


FIG. 18.—*Load-stress curves for pintle*—Continued

post is compression in every case, while the third post shows tension at all points. The curves for the second and the fourth post reveal a different condition. Gage lines *P 3*, *P 13*, and *P 23* on the front side of the second post show compression, while the other side of this post is found to be in tension. On the fourth post the odd-numbered gage lines show a small tension and the even-numbered ones show compression. It will be recalled, however, that the even numbers are on the front side of the fourth post, and if the pintle acts as a unit the stresses on this side should correspond to those shown by the odd-numbered gage lines of the second post. The curves show this to be the case.

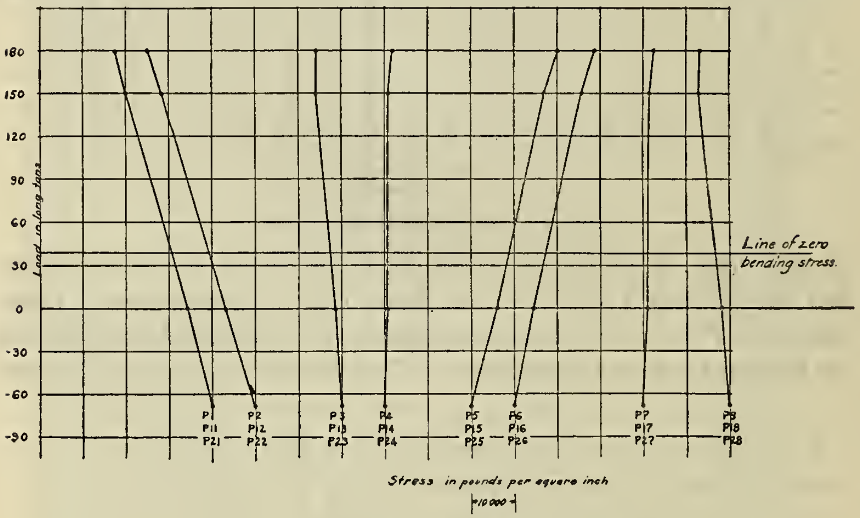


FIG. 19.—*Average load-stress curves for pintle*

Behavior of the Pintle Under Load.—The principal conclusion to be drawn from the individual curves is the fact that the stresses indicated by corresponding gage lines at the different levels are practically equal. The study of the stress distribution in the pintle can be more readily accomplished with the aid of the average curves, which are shown on Figs. 19 and 20. Fig. 19 shows the average value of the three levels for each side of each post. The irregularities of the individual curves are considerably reduced by this method of averaging. The left side of the first post (*P 1*, *P 11*, and *P 21*) shows a slightly smaller amount of stress than the right side (*P 2*, *P 12*, and *P 22*) of the same post, the stresses being 22 500 and 25 000 pounds per square inch, respectively. The front side (*P 3*, *P 13*, and *P 23*) of the second post shows a compression stress of 6000 pounds, while the rear side (*P 4*, *P 14*, and *P 24*) shows a tension of 2000 pounds at the same load.

Magnitude of the Stresses in the Pintle.—The rear post (No. 3) shows maximum tensile stresses of 20 000 pounds and 19 000 pounds per square inch on the right and left side, respectively. The fourth post behaves very similarly to the second post, showing a compression of 7000 pounds per square inch on the front side and a tension of 2500 pounds per square inch on the rear side. The compression in the front side and the tension in the rear sides of the side posts (Nos. 2 and 4) are in agreement with the stresses found in the front and rear posts of the pintle, thus indicating that the pintle acts as a unit with neutral plane passing through the side posts.

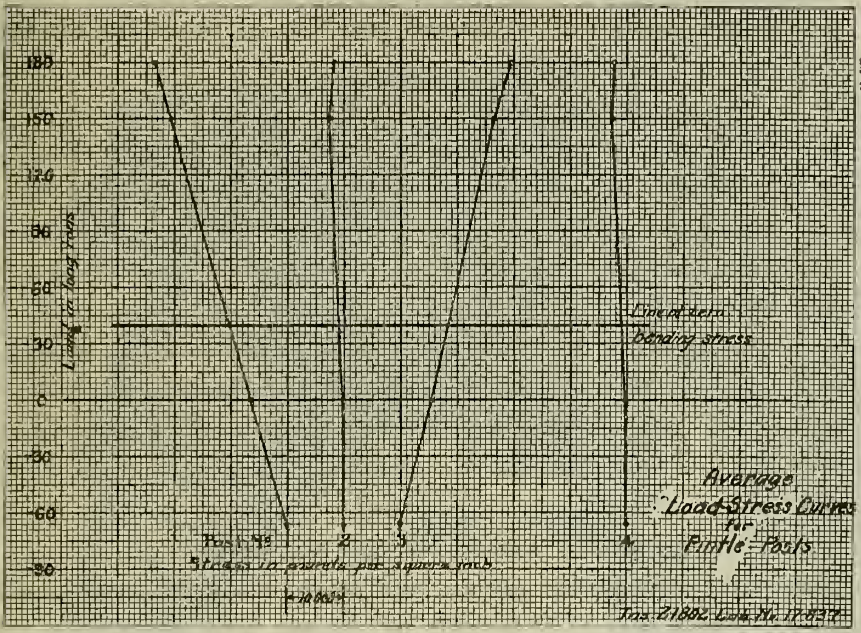


FIG. 20.—*Load-stress curves for pintle posts*

Fig. 20 shows the average of all the gage lines of each post. Curve No. 1 shows a maximum compression of 23 500 pounds; No. 3 a corresponding tension of 19 500, while the side posts Nos. 2 and 4 show a compression of approximately 2000 pounds at the 180-ton load. Considered algebraically, it is seen that if a compression of 2000 pounds per square inch is subtracted from all the values indicated by the curves for the 180-ton load, the compression and tension in the front and rear posts will be equal and the net result for the side post will be a zero stress. This suggests that the compression of 2000 pounds per square inch was due to the additional weight of 180 tons applied to the pintle.

Just as the range of stress shown for the tower members did not necessarily indicate an actual tension or compression of such an amount, so also the range of stress shown for the front and rear pintle post may be divided into tension and compression. Measuring the stresses from the 40-ton load line results in an indicated compressive stress of 13 000 pounds per square inch in the forward post (No. 1), and an indicated tensile stress of 11 000 pounds per square inch in the rear post (No. 3), under the 180-ton load. With the jib up and no load on the hook, the stresses are 10 500 tensile and 8500 pounds per square inch compression on the front and rear posts, respectively.

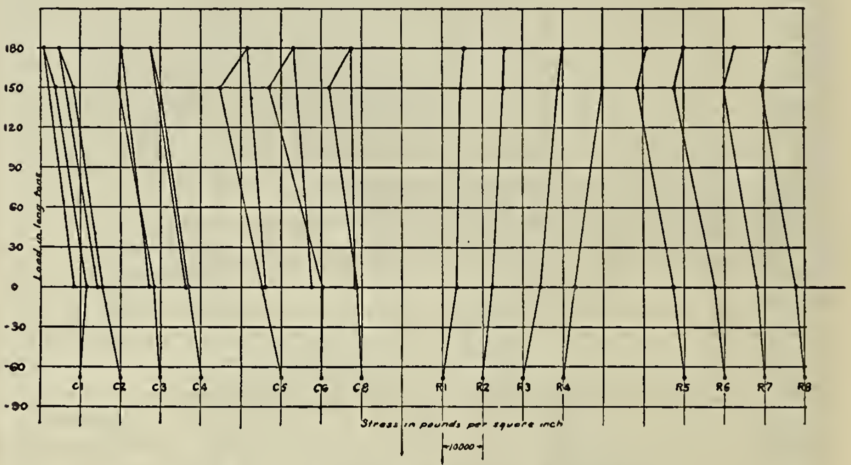


FIG. 22.—*Load-stress curves for superstructure*

The direct stress due to dead and live load is approximately 5000 pounds per square inch compression. This stress must be added, algebraically, to the above values, due to bending, which results in a maximum compressive stress of 18 000 pounds per square inch in the front post and 13 500 pounds per square inch in the rear post. This is not excessive for a structure under 20 per cent overload. The maximum tensile stresses are only 6000 and 5500 pounds per square inch on the front and rear posts, respectively.

(*d*) *Superstructure*.—The locations of the gage lines on the superstructure are shown on Fig. 15. The load-stress curves for the individual gage lines will be found in Figs. 22 and 23. Al-

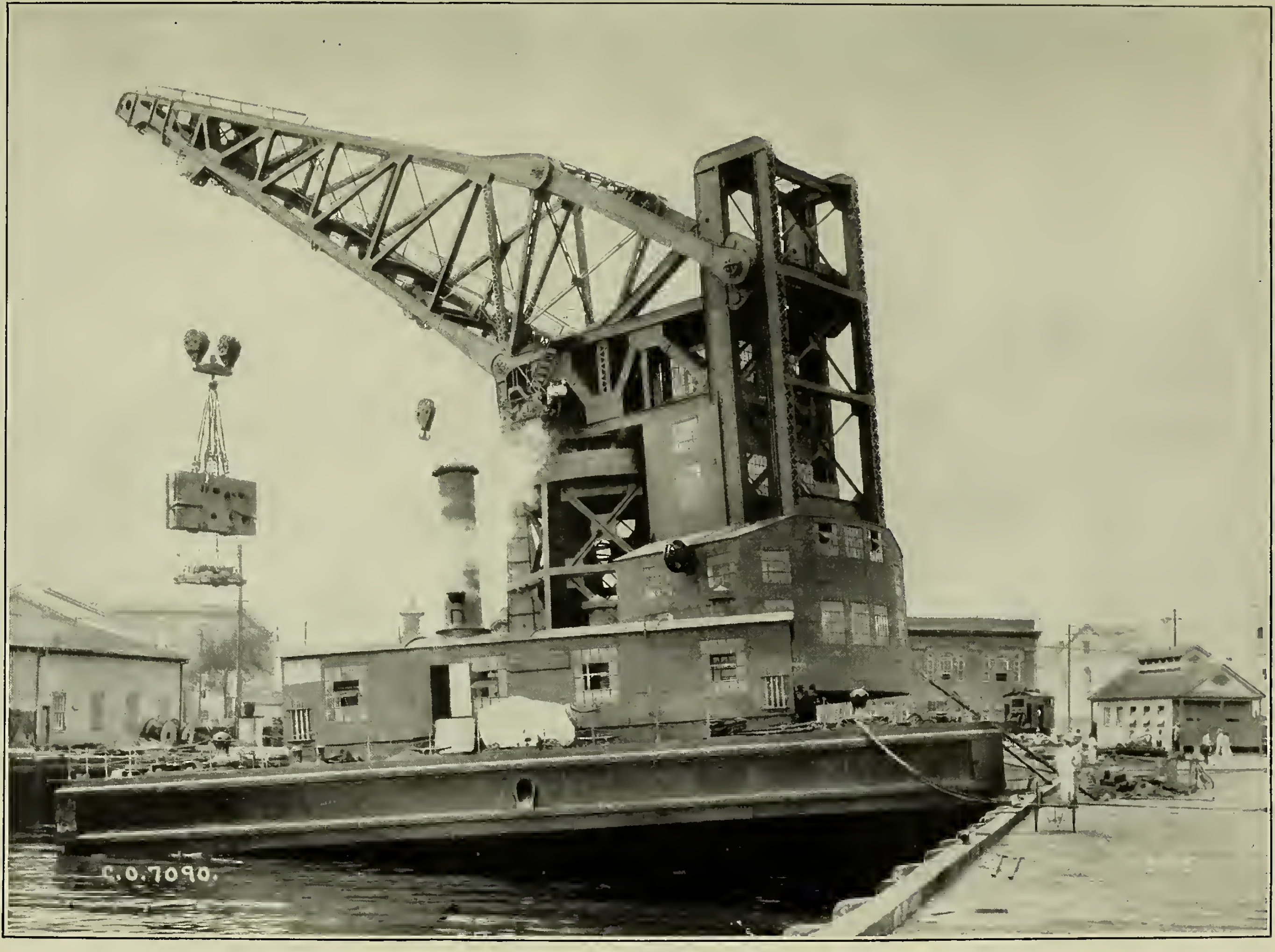


FIG. 21.—*Crane under load of 180 tons, load swung to port*

though several of the groups of curves do not show a straight-line relation of load to stress, still it will be seen that the curves in each group are quite similar and in most cases nearly parallel. Any bending in the members would result in a non-uniform stress distribution across the section giving curves which are not parallel.

Vertical Posts of the Superstructure.—The most noticeable bending is shown by gage lines *R 13* and *R 14* on the vertical post of the side truss of the superstructure. The rear side (*R 14*) of this member is found to be in compression while the front side shows a slight tension. This would indicate that the member was bending with the concave side toward *R 14*. An examination of the stresses in the adjacent members reveals that both diagonals framing into the top of the post exert forces toward the rear of the superstructure. These would naturally cause a bending in the post in the direction indicated by the readings, provided this post was somewhat fixed at the bottom, a very logical assumption for a riveted member.

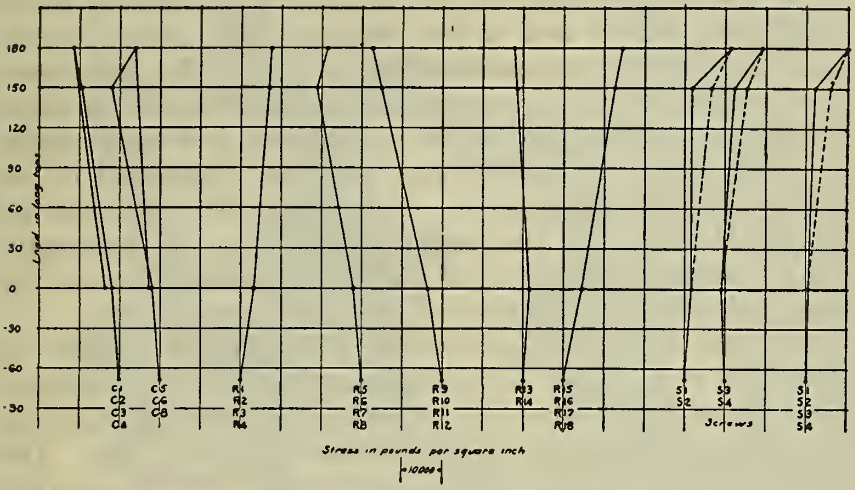


FIG. 23.—*Average load-stress curves for superstructure and screws*

The behavior of the structure under load is more evident from the average curves for the various members. These are shown on Fig. 23.

Jib Members.—The stress in jib members (*C 1*, *C 2*, *C 3*, and *C 4*) is nearly proportional to the load applied to the jib, attaining a maximum value of only 12 000 pounds per square inch. The discrepancy in the two readings at the zero load may be partially due to a slight difference in the height to which the jib was luffed when these readings were taken.

Struts for the Luffing Screw Guides.—The behavior of the compression strut supporting the guides for the luffing screws is apparently very erratic, the stress caused by the 150-ton load being 12 000 pounds per square inch while the 180-ton load produces a compression of only 6000 pounds. From the drawings of the structure it will be seen that the horizontal component of the tension in the links which support the jib produces no effect in the strut under discussion except when the jib is near its lower position. In lowering the jib after this position is reached, at which the strut commences to take a portion of the link load, the load carried by the strut varies rapidly with a small change in the position of the jib. It will be recalled also that the position of the jib was determined by the clear reach of the crane hooks beyond the side or end of the pontoon. The amount of list must increase with the magnitude of the hook load. It is therefore evident that with a load of 180 tons the jib would be luffed to a higher position than for the 150-ton load, and consequently a smaller portion of the link load would be transmitted to the compression strut in question. It is quite conceivable that the proportion of the link load carried by the strut was sufficiently reduced by the slight raising of the jib to make the stress in the strut less for the 180-ton than for the 150-ton load.

Side Diagonals of the Superstructure.—The diagonal member on which *R 1*, *R 2*, *R 3*, and *R 4* were located, shows a stress proportional to the load. The stress is tension, as would be expected, and reached a maximum of 7000 pounds per square inch. The next curve for gage lines (*R 5*, *R 6*, *R 7*, and *R 8*) represents the stresses obtained in the front or first diagonal of the side truss. The behavior of this member is not readily explained and is in fact contrary to expectations. Aside from the fact that the stress is not entirely proportional to the load, it is found that the stress in the member is compression, instead of tension, as had been anticipated. Apparently the only plausible explanation for this is that the horizontal reaction on the front pintle post is carried by beam action in the lower chord of the end truss to the side trusses, thus producing a compression in the lower chords and the end diagonals of these trusses. If the compression thus produced in the diagonals is greater than the tension produced by the load transmitted through the vertical corner posts, the resulting stress in the member would be compression as indicated. It is impossible to state definitely the way in which the loads are carried by this complicated, indeterminate structure, without

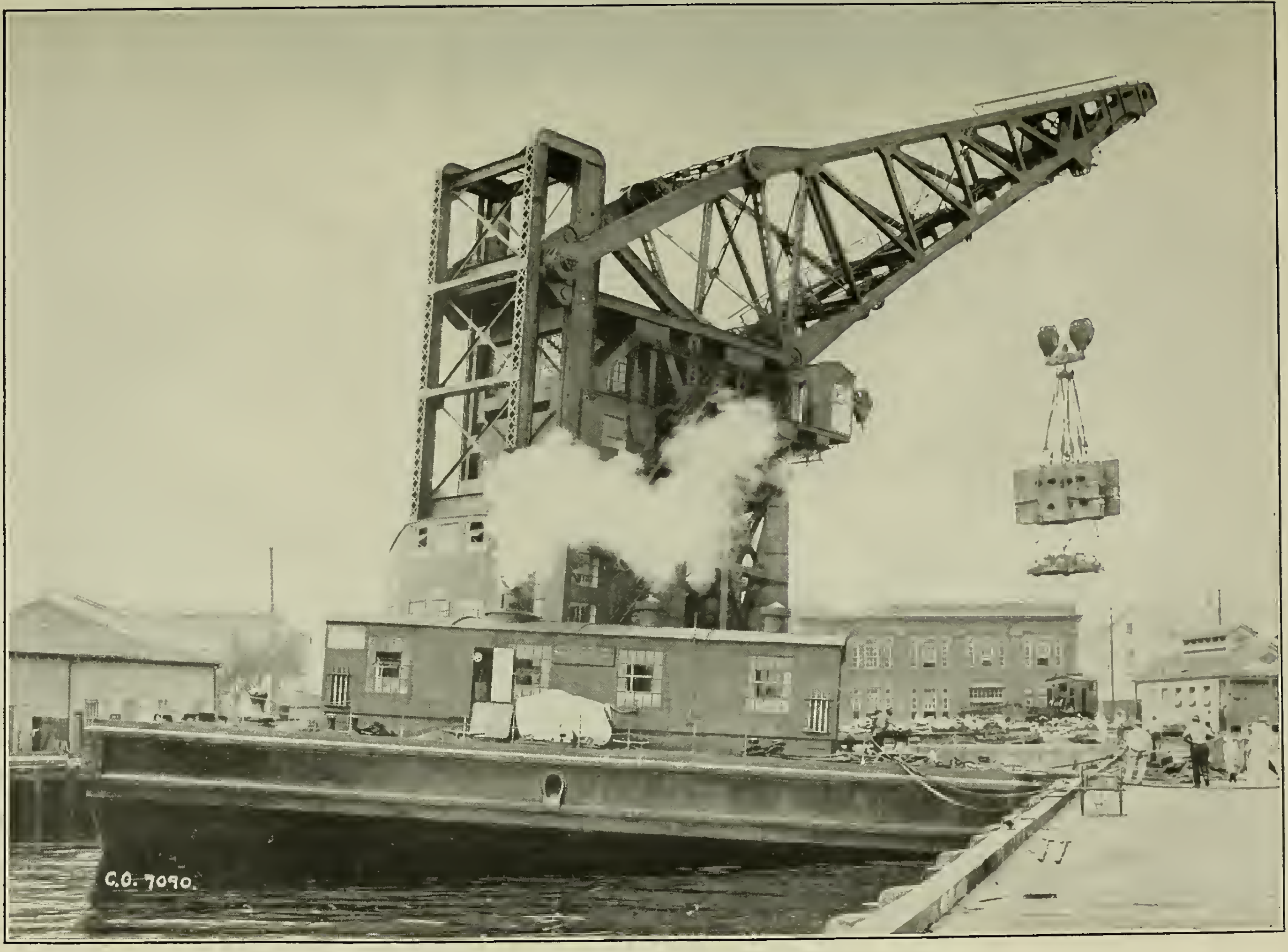


FIG. 24.—*Crane under load of 180 tons, load swung to starboard.*

stress measurements on some of the other members, such as the lower chords of the trusses and the front corner posts.

Front Diagonals of the Superstructure.—The stress in the diagonal of the front truss is shown by the average curves for gage lines *R 9*, *R 10*, *R 11*, and *R 12*. A maximum compressive stress of 17 000 pounds per square inch is indicated. The vertical post, on which gage lines *R 13* and *R 14* were located, apparently carried a very small load in direct stress, the maximum average compression being only about 2000 pounds per square inch. As has been previously stated, this member was subject to considerable bending, which resulted in a fiber stress of about 7000 pounds per square inch at gage line *R 14*. The extreme fiber, which was considerably farther from the neutral axis than gage line *R 14*, was undoubtedly more highly stressed than 7000 pounds per square inch.

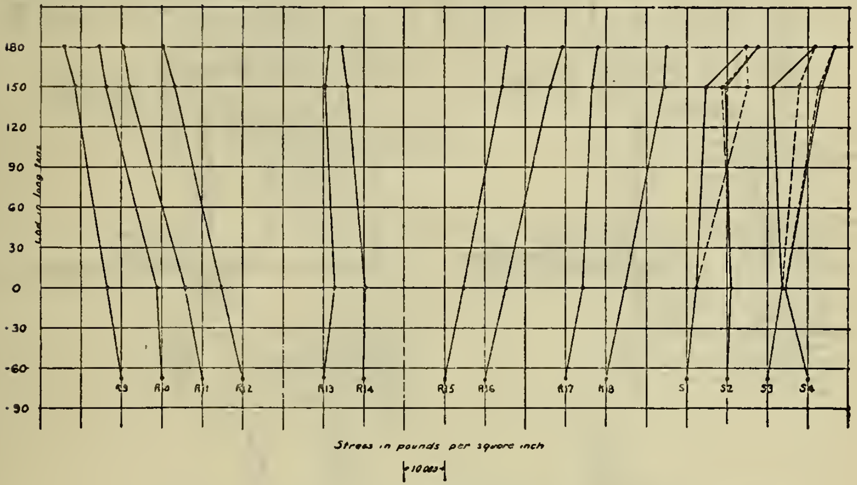


FIG. 25.—*Load-stress curves for superstructure and screws*

The stress in the diagonal of the truss, which frames into the rear pintle post, is shown by the average curve of *R 15*, *R 16*, *R 17*, and *R 18*, and amounts to 14 000 pounds per square inch in tension. From the framing of the structure it would appear that the stresses in the diagonals of the end trusses should depend upon the stress in the front and rear pintle posts. It is found that the ratio of the stress in the diagonal to stress in the corresponding pintle post is almost exactly the same for the diagonals in the front and rear trusses.

(*e*) SCREWS.—The results of the observations on the screws shown in Fig. 25 indicate a peculiar behavior. Considering the portion of the curve above the zero line it would be expected that the stress should increase approximately with the load applied at the hook of the jib when the jib is in practically the same position. Two sets of readings are shown for the 150-ton load, the full-lined curves showing the first set and the dotted line the second set. The individual curves for either set are very irregular, and in some cases the indicated stress is less for the 150-ton load than for the zero load, while others show a large increase in stress over this same range. The large difference in the stress observed on the opposite sides of the same screw must be due to bending in the screws.

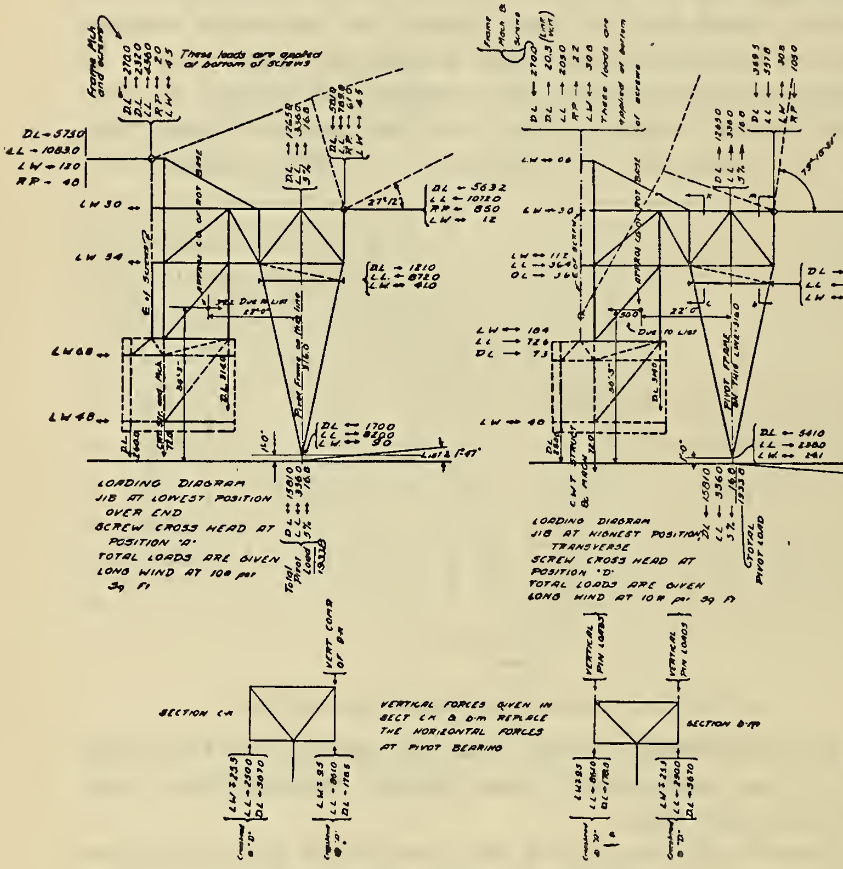


FIG. 26.—*Stress sheet of crane.*

The average for each screw and the average of both screws are shown on Fig. 23. The behavior of the two screws is seen to be

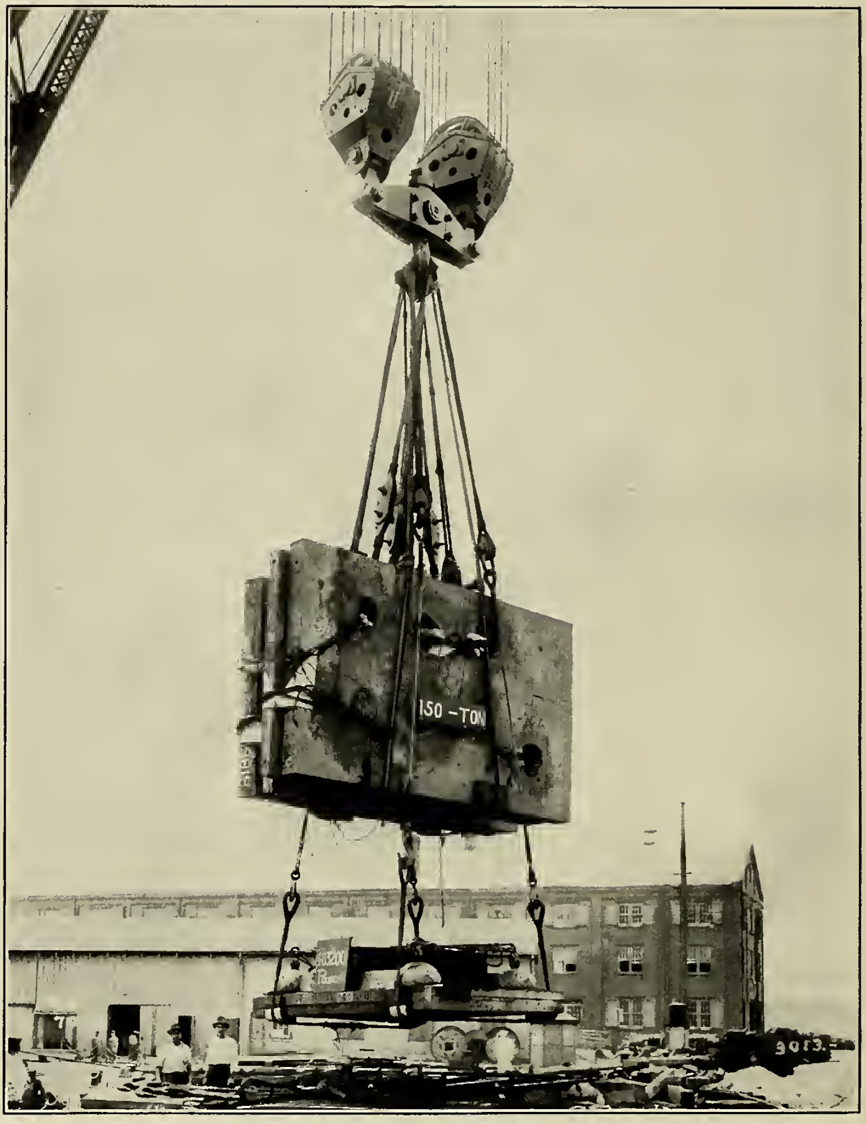


FIG. 27.—*Weights forming load at 180 tons.*

very similar. The stress at the 150-ton load is apparently low, and it will be noted that the second set of readings gives much more reasonable looking results than the first set. From this it might be concluded that the friction on the guides carried a portion of the vertical load for a time, but that by the time the second set of readings was taken the load had been released to screws. It should also be noted that the jib was luffed up or down at each load until the proper reach was attained. It is therefore impossible to state in which direction the jib had been last luffed before the readings were taken. The direction of luffing would greatly affect the stresses in the screws, if the friction on the guides was appreciable.

IV. SUMMARY AND SUGGESTIONS

1. SUMMARY

1. Although the test conditions were not ideal, the consistency of the results is sufficient evidence that in general they are dependable.
2. The stresses in the deck of the pontoon are very small under any of the conditions of load and position of the jib investigated.
3. The range of stress in the outer edges of the tower legs for the 180-ton load is from 17 000 pounds per square inch in compression to 13 500 pounds per square inch in tension.
4. The maximum compressive stresses, including the dead load, in the front and the rear pintle posts are 18 000 and 13 500 pounds per square inch, respectively, for the 180-ton load.
5. The stresses in the superstructure are not excessive unless the dead-load stresses are high.
6. The indicated stresses in the screws are rather uncertain but apparently not excessive.

2. SUGGESTIONS

Should more accurate and detailed information on the behavior of such a structure be desired, the following suggestions should prove valuable:

1. The strain-gage observations should, if possible, be made at night or on cloudy days unless it is practicable to shade the entire structure. Standards bars should also be used.
2. The true zero for the stresses in the tower should be determined either by taking readings with the jib in two positions

180° apart or by balancing the counterweight with a live load on the hook.

The stresses for zero bending in the pintle should be determined by balancing, as suggested above.

3. The stress distribution in the superstructure should be determined by observations on all the principal members instead of the few that were used in this test.

WASHINGTON, June 19, 1919.

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